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VIII. *The Bakerian Lecture. On certain motions produced in fluid conductors when transmitting the electric current.* By J. F. W. HERSCHEL, Esq. F. R. S.

Read February 12, 1824.

1. HAVING had occasion, in the course of some enquiries respecting the decomposing agency of the Voltaic pile, to electrify mercury in contact with various saline solutions, I was surprised to observe motions take place in the fluid metal of a violent and apparently capricious kind, for which, as I had uniformly operated with very feeble electric powers, there seemed no adequate cause. Frequently it would be agitated with convulsive starts; sometimes currents and eddies of great violence would be formed in it; at others, it would spread and elongate itself, ramifying out into the most irregular forms; and altogether presenting appearances of a nature so singular, as induced me to make experiments with a view to ascertain their cause, or at least the circumstances essential to their reproduction.

2. The singular convulsive agitations into which mercury is thrown when placed within the circuit of a powerful Voltaic battery discharged through water, has been noticed by Sir H. DAVY, in his Elements of Chemical Philosophy. Pure water, however, is so very imperfect a conductor, that great Voltaic powers must be used; and the phænomena are then too irregular, and the agitations too violent for distinctness.

It is only when liquids which conduct well are used to form the circuit, that they become regular, and can be studied at leisure under the influence of moderate electric energies.

3. If a quantity of very pure and perfectly clean mercury, free from the slightest superficial film, be placed in a Wedgewood-ware evaporating basin (which must also be scrupulously clean), and covered to the depth of about a quarter of an inch with concentrated sulphuric acid, and the extremities of two wires of platina in connexion with the poles of a Voltaic\* apparatus be immersed *in the acid only* on opposite sides of the mercury, but not in contact with it; immediately a rapid circulation will be seen to take place in the acid, owing to a violent current which establishes itself between the two wires, setting directly across the mercury in a direction from the negative (or zinc) towards the positive (or copper) pole. This current is kept up steadily, and without any change in its direction or force so long as the pile remains in activity, and only flags, and at length ceases, when its energy is quite exhausted. The mercury is not sensibly tarnished or otherwise acted on, and, after the experiment, is found to have undergone no change; nor is the acid sensibly altered, with the exception of the trifling portion decomposed, and a minute quantity of mercury taken up.

4. If we examine the phænomena more attentively, we shall observe that the particles of the acid in immediate contact *with the mercury*, are those which move most actively, being

\* The battery I employed in this and the subsequent experiments (unless where the contrary is expressed), consisted of ten pairs of single plates, each of fourteen square inches in surface, excited by mixed nitric and sulphuric acids much diluted.

darted along its surface with surprising violence ; those above them, and more remote, appearing rather to be dragged or forced along by them, than impelled by any force acting directly on themselves. We shall perceive too, that, if some distance intervene between the wires and the edges of the mercury, the current will be confined, and the circulation take place in the immediate neighbourhood of the mercury *only*, the liquid around the wires being nearly, or quite at rest.

5. If the centre of the globule or disc of mercury be situated in one straight line with the extremities of the wires, the current will set diametrically across it ; but if this be not the case, it will follow a curvilinear course, every elementary filament of it having a different curvature, and each traversing the mercury in a path having a common origin and termination, viz. the points (*z*) and (*c*) of its surface nearest to the negative and positive poles respectively.

6. If the globule of mercury be of considerable size (four hundred or five hundred grains for instance), it will be observed to elongate itself in the direction of its axis towards the negative wire, and if near enough, will reach and amalgamate with it : but if it be small, its whole mass will move bodily with more or less rapidity, as if attracted to the negative wire. This apparent attraction is often very energetic, the globule moving with great velocity towards the negative wire, to which it immediately adheres. If the wires form a triangle with the situation of the globule while at rest, the latter advances neither directly to the negative, nor directly from the positive wire, but in a direction oblique to both, approaching the negative wire in a spiral, and describing frequently several revolutions with increasing velocity before it

ultimately falls into and amalgamates with it, like a body acted on at once by an attractive force tending to the negative, and a repulsive, from the positive wire.

7. These apparent attractions and repulsions, this elongation of large masses of mercury and bodily motion of small ones toward the negative pole, are in reality, however, only secondary effects ; their immediate cause, as well as that of the currents in the surrounding acid, will be discovered by a more minute attention to what takes place in the mercury itself, while under the influence of the electric action.

8. To this end, if we operate on a considerable mass of mercury, and, instead of covering it with the acid, merely moisten it and the containing vessel, making the circuit as before, only by the medium of the thin film of acid which adheres, the circulation of the mercury will be not less violent; but it will then be evident that the origin of the motion is in the mercury itself, the acid film being (so far as mechanical impulse is concerned) merely passive, and dragged along by its adherence to the mercury, coating it frequently with a stratum so thin as to reflect iridescent colours over its whole surface, and render the phænomenon extremely beautiful. The motion of the mercury consists in a continual radiation of its superficial molecules from the point nearest to the negative pole, by which it is kept in a constant state of circulation, each particle being urged along the surface from the negative to the positive pole and returning along the axis. Were the mercury insulated from contact with the bottom of the sustaining vessel, and devoid of adhesion to the liquid, the momentum of the portions going and

returning would be equal, and the centre of gravity of the whole mass would remain at rest; but by reason of the friction and adhesion of the fluid metal to the vessel and liquid, these re-act on the globule in a direction contrary to that of the superficial currents, and the centre of gravity accordingly advances in that direction, or towards the negative pole. When this motion cannot take place, the internal current, having all one uniform direction, forces its way outwards to the negative pole, distorting and elongating the figure of the mercury in proportion to its energy. If the metal be oxidated, so as to give a certain tenacity to the superficial film, the radiating currents pursue their course under it; and the supernatant fluid, being thus defended from their action, remains at rest. In this case the only indication of their existence is the protuberance produced by the resultant interior streams.

9. A number of singular appearances are explained by this internal current. In some cases the mercury throws out projections or proboscis of inordinate length, which take the direction of the electrified wire, and follow all its motions. The resultant interior current is in this case directed along the axis of the proboscis from its root to its extremity, which thus becomes an indication of a very powerful radiation along its surface in an opposite direction. In others, the mercury flattens throughout its whole extent, and, when this is the case, it is always covered with a thick coat of oxide. In these circumstances the superficial currents tend from the circumference towards the centre of the flattened mass, and the interior stream tends from the centre outwards in all directions,

in a horizontal plane, thus continually urging the circumference farther and farther out, by diminishing the radius of curvature of the vertical section of its edge.

10. That friction against the vessel is the principal cause of the apparent attraction of a globule of mercury to the negative end, may be proved evidently by the substitution of a glass for a Wedgwood-ware basin. In this case the currents are produced as before ; but, though equally forcible, the globule shows little or no tendency to move bodily, but if placed on a plate of emeried glass, or on any other rough surface, it will move with great activity ; nay, so strong is its tendency to the negative pole, that globules of considerable magnitude may thus be sustained without contact of either wire, on surfaces many degrees inclined to the horizon.

11. It is essential to the production of the motions in question, that the mercury be in actual contact and free communication with the acid, and so situated as to be within the influence of the electric current. It is not necessary, however, that a continuity of the acid should subsist between the positive and negative wires ; they will appear in any interrupted circuit of mercury and the liquid medium. The experiment indeed is difficult to try in sulphuric acid, whose capillary attraction for mercury is such that the least drop, applied to any part of a clean surface of that metal, instantly spreads over the whole, but with other conducting media it may readily be made. We have only to drop a little of the liquid to be tried on two different spots of a large clean surface of mercury, and bring the poles in contact with them, taking care not to plunge them in the metal, when the same phænomena will be observed to take place about each pole as

if the whole surface had been covered with the liquid. The motions however are confined to such portions of the mercury as are actually covered, all the rest remaining quite still: the effects too are modified by capillary action.

12. When the circuit is completed in a conducting liquid, in the manner described in the beginning of this paper, the action is most forcible in the direct line joining the poles; its violence diminishing as we recede from this line, though it continues sensible to a great distance either way: and the course pursued by electricity in its passage through conducting media, and its law of distribution within it, may in some degree be traced, by placing globules of mercury in different parts of a liquid; when it will be plainly seen, that it is by no means confined, or nearly so, to the straight line between the poles, or to the surface of the conducting medium, but immediately on quitting the wires diffuses itself through the whole liquid, its density being a maximum in the space directly between them, and diminishing rapidly as we recede from their line of junction.

13. The mechanical action appears (*cæteris paribus*) to be proportional to the absolute quantity of electricity which passes, *dato tempore*, through a filament of the liquid at the point where it is exerted. The magnetic effect is proportional (*cæteris paribus*) to the absolute quantity of electricity in motion present at once, (or at any indivisible instant of time) in a given portion of the conducting wire, or within the sphere of action of the needle, that is, to its density.\* To establish or

\* In these expressions I have conceived electricity as being transmitted through conductors according to the laws of a gas of high, but variable elasticity through pipes more or less obstructed, a supposition which will represent many of the

refute this distinction, will require experiments which it is easy to imagine, but which I have not yet had an opportunity of making. At first sight, indeed, the phænomena in question present a considerable analogy to the electro-magnetic vortices observed in the fluid metals; but on presenting very powerful magnets to the mercury, while under the circumstances above described, in various positions, I have never been able to perceive any influence exerted by them in accelerating, retarding, or deviating the currents; and moreover, these are incomparably more forcible in proportion to the electric powers used, than the motions produced by the action of magnets.

14. In consequence of this superior energy of action, the phænomena which form the subject of this Paper, furnish a test, perhaps, the most sensible yet known of the developement of feeble Voltaic powers. I constructed a small battery of zinc and copper wires twisted together, each pair being two inches long from the point of junction, and the wires  $\frac{1}{30}$  of an inch thick. Ten pairs of these, excited by extremely dilute nitric acid, caused a rapid rotation in mercury, interposed under sulphuric acid between the poles, and a regular advance of

phænomena. The sluggish electricity of a single pair of plates may be compared to air, rendered dense and less elastic by excessive cold, while the active charge of a powerful battery, or the spark of an ordinary electrical machine, is in this view assimilated to air with all its energies exalted, and its density diminished by violent heat. The same quantity in weight may pass through the same conducting pipe in the same time; but in the one case the motion of each molecule will be comparatively much slower, and the actual quantity present at any instant of the discharge (e. g. an inch in length) of the conductor, much greater than in the other. I am well aware that this is merely an analogical representation of facts, and of course inaccurate, but it serves to explain the distinction in the text.

globules of that metal towards the negative pole. The rotation continued with considerable force, when the wires were so far withdrawn as to have only their extremities in contact with the liquid in the cells, in which case the surface exposed by each pair to the action of the acid could not exceed  $\frac{1}{50}$  of a square inch. Nay, so delicate is this indication, that the electricity developed by bringing the extremities of a thin zinc and copper wire in contact with a glass merely moistened with the above mentioned dilute acid, is abundantly sufficient to cause an immediate and unequivocal rotation in an ounce or two of mercury properly exposed to its action. By this means, indeed, the feeblest electrical excitement may be placed in evidence. I have thus rendered *strikingly* sensible the electricity developed by a mere difference in the state of the surface of two small portions of copper wire from the same coil (one being a little cleaner than the other) not above an inch in length of either being immersed; or that set in motion by a copper and zinc wire held near together and dipped in common pump water, powers which it is not easy to render sensible by other means. For the success of these experiments, however, it is not enough merely to plunge the extremities of the conducting wires under sulphuric acid. The surfaces of contact *here* require to be greatly increased,\*

\* The efficacy of an increase of surface for transmitting electricity *into* a liquid, is remarkable. By bringing the positive pole in contact with a large surface of mercury, or still better, of an amalgam of mercury and zinc, over which a saline solution is poured, the reduction of the metals of the alkalies and earths at the other pole is operated with a degree of facility hardly to be imagined without trial. In this way the decomposition of ammonia may be effected with three pair of single plates of the above dimensions, in very moderate action.

so as to insure the transmission of the whole of the electricity developed. The best way is to immerse them in two considerable pools of mercury under the acid, one on either side of the globule to be set in rotation.

15. Hitherto we have considered only the effect produced when a current of electricity is transmitted over mercury through sulphuric acid. When other conducting liquids and other metallic bodies are used, phænomena of the same kind are produced, but so modified by the nature of the substances employed, the intensity of the electric power, and the manner of conducting the experiments, as to become extremely perplexing; and I must warn the reader who may be inclined to repeat them, that he must expect to find them frequently fail, or even give contrary results from those I shall describe, owing to causes by no means easy to discover. The principal is impurity in the mercury used, and none should be used but what has been carefully distilled, and well washed with dilute nitric acid. It was long before I discovered this necessity; and ignorance of this essential condition engaged me in a series of tedious and disheartening repetitions of every experiment, till I was on the point of relinquishing the subject in despair, encountering contradictory results in operations conducted, as I then supposed, in a manner precisely similar.

16. When mercury, so purified and perfectly clean, is placed in any conducting liquid, and the circuit completed without bringing either pole in contact with the metal, the phænomena vary with the nature of the liquid; but, generally speaking, the effect is the production of currents more or less violent, radiating from the point nearest the negative pole.

In the acids, particularly in the more powerful and concentrated ones, and such as are good conductors of electricity, they are decided and violent. In saline solutions their force is less, in proportion as the electro-positive energy of the base is greater. Thus, in the salts with a basis of potash they are feeble, and often only perceptible by a momentary start of the mercury when the circuit is completed. In those of soda, ammonia, baryta, strontia, and lime, they are more distinct, while in salts of magnesia, alumina, and the metallic oxides, their influence is still more sensible. On the other hand, under solutions of the pure alkalies and alkaline earths, the mercury remains quite quiescent, or at most is only agitated by feeble and irregular motions, depending on causes not now in contemplation.

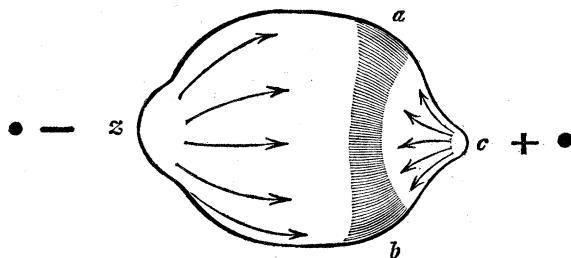
17. In many liquids, and especially in solutions of the nitrates, there is formed not only a current radiating from the negative pole, but also one from the positive, which even has in some cases a preponderance over the other. These co-exist in the mercury ; and, in consequence of their action, a zone of equilibrium is formed in the globule, nearer to one or the other pole, as the antagonist current is more or less violent. The best way to render the influence of this counter-current sensible, is to operate on a large quantity of mercury, under dilute solutions, keeping the negative pole at a distance, and the positive very near. In this way there are few liquids which, when the pile is in good action, do not show some signs of a counter-current from the positive pole. The cause of this will be evident, when we come to speak of the action of metallic alloys.

18. If either pole be brought in contact with the mercury, no

currents are observed from the point of contact (at least when the mercury is fresh and the contact perfect) but strong ones are always produced, radiating from the other. If it be the negative pole which is made to touch, it amalgamates with the mercury, which remains bright, and the currents radiating from the positive are visible to the eye, and generally very powerful. On the other hand, if the positive pole be in contact, the oxidation of the metallic surface is usually so rapid as to prevent the currents becoming visible, but a momentary start of the surface from the negative wire, the flattening of the globule, and the protuberances it throws out in pursuit of the oppositely electrified conductor, sufficiently indicate their existence under the crust of oxide. Where this oxidation however does not happen, or is prevented by the addition of a few drops of dilute nitric acid, the currents from the negative wire are equally evident with those from the positive, just mentioned.

19. These however are not the only effects produced by contact with the electrified wires. On breaking the contacts and completing the circuit in the liquid, the mercury is found, for the most part, to have acquired new properties, or lost some of its former ones. A globule of four or five hundred grains of pure mercury being introduced into a solution of sulphate of soda, the circuit was completed in the liquid with neither pole in contact. A current was produced from the negative pole. A momentary contact being made with that wire, and the circuit then completed as before in the liquid, a counter-current was produced from the positive pole, more confined in the sphere of its extent, but apparently more violent in its action than that from the negative. In conse-

quence, the globule acquired the figure here annexed, having a blunt elongation at  $z$ , the point nearest the negative pole, and a more pointed one at  $c$ , that next the positive, with a kind of shoulder at  $ab$ . The film of oxide produced at  $z$



was thus swept towards  $c$ , but never attained beyond the zone  $ab$ , where it remained stationary and constant in quantity, being absorbed at the side next  $c$  as fast as it was produced at the other. Another short contact was now made with the negative wire, and, on breaking it, the currents from  $c$  were found to have increased both in strength and extent, while those from  $z$  were proportionally enfeebled, the zone of equilibrium  $ab$  being thus brought nearer to  $z$ . By another contact prolonged a few seconds, the negative currents were contracted within a very small space around  $z$ , and by prolonging the contact a little longer, its influence was totally destroyed, and a regular and violent circulation from  $+$  to  $-$  established throughout the whole globule.

20. But the effects did not stop here. On prolonging the contact a considerable time, the negative current (from  $z$ ) was not only wholly destroyed, but changed into one of a contrary tendency; *i. e.* radiating in all directions to  $z$ ; the particles of the mercury appearing to be attracted to that point with a force equal, or superior, to that with which they were

repelled from *c*. The positive pole being held at some distance, and the negative directly over the surface, any scum or impurity on the mercury was observed to collect directly under it, in a small circular spot, following exactly its motions ; and when this was cleared away, the fluid metal was violently thrown up towards the wire in a jet of two or three tenths of an inch in height.

21. The mercury was now brought into contact with the positive wire. Visible oxidation did not commence on its surface for a long while, during which time violent currents still continued to radiate in all directions from the wire and *towards* the point *z* (or in a direction opposite to what they would have taken in untouched mercury). By degrees, however, a counter-radiation commenced opposite to the negative pole, whose sphere was at first very limited, but gradually extended, producing a zone of equilibrium, which advanced rapidly towards the positive wire, and at length attained it. The instant this took place, the oxidation of the mercury commenced at *z*, and speedily extended over the whole surface, forming a thick crust.

22. If the contact of the positive pole was continued long enough, the mercury, on cleansing it from its coat, was found reduced to its former state, as if freshly introduced ; but if broken as soon as the crust was fully formed, a radiation from the negative wire was produced, and the crust broken up and swept by it to *c*, where it collected, and was hurried off. But the moment this was done, and the surface of the mercury had become bright throughout, it stopped for an instant, and immediately a violent revulsion took place and a powerful current radiated from *c*, that from *z* being annihilated.

23. These effects, when first observed (not connectedly in regular succession, as here set down, but piece-meal), appeared exceedingly perplexing ; but the key to them was soon found. I observed that the effect of a contact of the negative pole was proportionally stronger in producing a positive radiation, as the mercury had been allowed to circulate longer before the contact was made, and, on more close examination, I found that the platina wire terminating the negative conductor of the pile, had got amalgamated with a little mercury, which, during the time the circuit was completed in the liquid, had become alloyed with sodium ; and, with the quantity of this metal judged to be present, the effect seemed always to be in proportion. I had no hesitation, therefore, in attributing all the new properties acquired by the mercury to the presence of sodium, and on introducing into a quantity of the pure metal a small quantity of an amalgam of this substance prepared for the purpose, I found my supposition verified ; a most violent negative rotation being immediately produced on completing the circuit, without allowing either wire to touch the mercury.

24. The presence of this highly electro-positive metal therefore counteracts the effect of the negative pole, and exalts that of the positive in a degree proportioned to its quantity, till at length it completely overcomes, and even reverses the former effect. As the quantity (in the foregoing experiment) diminished in the alloy by the oxidizing action of the positive pole, the mercury, as we have seen, by degrees resumed its original properties. The only effect that may appear obscure, is the revulsion noticed in the direction of the currents when the last portion of oxide disappears. It is, in fact, a pretty com-

plicated effect, but capable of easy explanation. The oxidation takes place over the surface of the metal before the last portions of sodium are removed. This is easily proved. We have only to break the circuit altogether, and the crust of oxide will gradually disappear (unless suffered to go too far), being reduced by the sodium beneath it. Were it then not for the crust of oxide, the currents, as has been seen, would be in a positive direction. But the oxide, acting on the stratum of metallic molecules immediately below it, deprives them of their alloy, which it converts into alkali, leaving a stratum of pure mercury. Now we have seen that in *this*, the rotation, in the circumstances of the experiment, would have a negative direction. We have only then to admit that the peculiar action by which the rotations are caused, is confined to the common surface of the mercury and liquid, to have a perfect idea of the mode in which the whole process is carried on. The stratum of pure mercury on the surface is removed by a negative current agreeably with its natural relations, and immediately succeeded by a stratum of the sodiuretted metal from the interior; this, in its turn, is deprived of its sodium by the oxide in contact with it, and is immediately radiated off like its predecessor, and so on till the whole crust of oxide is exhausted or swept off, when the remaining mercury, still retaining an excess of sodium, and instantly rendered homogeneous, is acted on as an alloy in the way already described.

25. That sodium is actually present in the mercury when it has acquired the property of producing currents from the positive pole, (which for brevity I will hereafter call the positive property) by contact with the negative wire, may be shown by

a very simple and interesting experiment. When the negative wire is detached and the circuit broken, the mercury lies quiet at the bottom of the vessel, with the exception of a slight irregular motion on its surface, and now and then a minute gas bubble disengaged. Now touch it under the liquid with a clean metallic wire of any kind (provided its extremity be not allayed with sodium), and a violent action instantly commences. The mercury rushes on all sides to the wire in a superficial current as if to give out its sodium, while a copious stream of hydrogen is given off from the wire, not merely at the point of contact with the mercury, but wherever it touches the liquid. In a word, the sodium, the wire, and the liquid form a voltaic combination, and the electricity produced by the contact is sufficiently powerful to decompose the aqueous portion of the latter in great abundance. The action lasts for a longer or shorter time accordingly as the mercury is more or less highly charged with the alkaline metal, rarely, however, for more than 10 or 12 seconds, and when over, the mercury is found to have lost its positive property, and to be reduced to its pristine state, (provided the contact be made with copper or platina), which a long immersion in the fluid without such contact would not have entirely effected.

26. If the mercury thus charged with the alkaline base be not entirely covered with the fluid, and the metallic contact be made at the vertex of the globule, out of the liquid, no effect is produced ; but if the other end of the metallic wire be bent round and brought to touch the liquid at some distance from the mercury, the violent action above described immediately commences ; with this difference, that *now* the surface

of the mercury is radiated in all directions *from* the point of contact to the circumference of the globule, and that the whole of the hydrogen is given off at the other end of the wire where it touches the liquid. A little consideration will suffice, however, to show that both these effects are merely modifications of one and the same. It is not to, or from the *wire* as such, that the superficial particles radiate ; they merely follow the direction of the predominant electric currents in their passage *through the liquid*. It is in fact the case of the source of positive electricity, being the mercury itself, instead of its being conveyed to it from a pile at a distance.

27. Having thus distinctly traced the alteration in the mechanical effect by contact with the negative pole, to the amalgamation of the mercury with sodium, the knowledge of this fact led me to investigate more minutely the effects of different metals in their contact and amalgamation with mercury ; and the results I have encountered in the course of these enquiries, appear to me so remarkable, that I cannot forbear annexing them, especially as they afford an explanation of almost every anomaly which perplexed me in the commencement of the investigation. In order to render the effects less liable to objection, as well as more distinct and striking, I now used solutions of potash or soda, pretty highly impregnated with the caustic alkali, for the conducting liquid. This has the advantages at once of high conducting power, and of producing no currents whatever in pure mercury, neither pole being placed in contact. Of course, whatever motions arise on the introduction of an extraneous metal must be due entirely to the presence of that metal, and the mercury may

be regarded as merely passive, so far at least as mechanical action is concerned.

28. *Potassium.* A contact of a single second's continuance with the negative pole of a pile of eight pairs, in feeble action under liquid potash, imparted to 100 grains of mercury the property of rotating violently from the positive to the negative pole, the circuit being completed in the liquid alone. The rotation was forcible when this alloy was diluted with 100 grains more of pure mercury, and was still sensible after the addition of another equal quantity. In this latter case, the quantity of potassium present could hardly be estimated at a millionth part of the whole mass.

29. *Sodium.* Under a solution of soda I electrised 100 grains of mercury during 80 seconds with the above mentioned Voltaic power, the mercury being in contact with the negative wire. It was then washed hastily, and introduced under a glass bell into dilute muriatic acid, which disengaged 95 mercury grain measures of pure hydrogen. Consequently, it contained less than  $\frac{1}{50}$  of a grain of sodium; and as in such extremely small quantities the production of the alloying metal must go on uniformly, a contact of 1" would have produced only  $\frac{1}{80}$  of the quantity, or  $\frac{1}{4000}$  of a grain; that is  $\frac{1}{400,000}$  of the whole mass. This being premised, a contact of 1 second in duration was made under similar circumstances, with 100 grains of fresh mercury, which was thus found to have acquired a powerful rotatory property. This was now diluted with 100 grains more of the pure metal, in which, therefore, the sodium was only in the proportion of 1 to 800,000. The rotation was enfeebled, but was still full and distinct. Being again diluted with 100 grains more of mercury, so as to make the propor-

tion of sodium 1 : 1,200,000, there was still a considerable radiation from the positive pole, but not extending over the whole surface. On reducing the proportion of sodium by a third addition of an equal quantity of the pure metal to 1 : 1,600,000, a feeble radiation was still sensible in the same direction.

30. *Ammonium.* A considerable quantity of the amalgam of this singular substance introduced into mercury under a solution of soda *did not communicate to it any power of rotation.* This remarkable result, which goes to separate ammonium by a definite character from the other metallic bases of the alkalies, was again obtained on repeating the experiment. It is possible, indeed, that a complete insolubility of the amalgam in pure mercury may be the cause of this want of action, but the supposition must be allowed to be a very forced one.

31. *Barium.* This metallic body amalgamates with the utmost readiness with a power of eight pairs of plates when the muriate is acted on; a small globule of mercury at the negative wire throwing out beautiful arborescences, and fixing into a highly crystalline, pretty permanent, solid amalgam. A very minute quantity of this introduced into mercury under solution of soda, gives it the positive property. Its efficacy, in reversing the direction of the currents, is strikingly sensible when introduced into a quantity of mercury kept in a state of negative rotation under oxalic acid. The amalgam of mercury and barium added in small quantities to pure mercury, imparts to it the same property as we noticed in the case of sodium, of forming a Voltaic combination with a wire brought in contact with it under a saline solution, and the action so produced is much more lasting.

32. *Strontium, Calcium.* These metals, in my experiments with the feeble powers used, manifested a remarkable indisposition to alloy with mercury. The small quantity of calcium deposited on an amalgamated negative wire obstructed its contact with a larger globule of mercury to such a degree, that no electric communication could be established. Under a solution of strontia, the contact of the negative wire imparted the positive rotatory property sensibly, though very feebly. That this was not merely owing to the low conducting power of the liquid, was proved by introducing a minute quantity of the amalgam of zinc, when the mercury immediately commenced rotating strongly. The influence of *magnesium* is more sensible than that of strontium or calcium, from the greater readiness with which it amalgamates.

33. *Zinc.* When pure mercury is electrified under solutions of potash or soda, with neither pole in contact, in the manner so often alluded to, it shows no signs of rotation, as has already been observed; but, if touched for an instant with the end of a clean zinc wire, or if an atom of the solid amalgam of zinc, the smallest that can be taken up on the end of a needle, be added to it, it instantly rotates violently in a positive direction (or from the positive pole).

34. An alloy of one part zinc to 10,000 of pure mercury rotates with the utmost violence. When this is diluted with ten times its quantity of the latter metal, the force of rotation appears but little impaired. The proportion of mercury was increased to 400,000 : 1, and the rotation, though feeble, was yet complete, pervading the whole of a considerable mass of the alloy; and even when the zinc amounted to no more than a 700,000th of the whole, a current radiating to a short dis-

tance from the positive pole was still sensible : when, however, the zinc formed only a millionth part, no difference could be perceived between the alloy and pure mercury.

35. *Lead.* An alloy of 200 parts of mercury and 1 of lead possessed the positive property in perfection. When the proportion of mercury was 667 to 1, the rotation was still produced, but was not full and regular. When increased to 1000, a slight, but sensible current, was perceived to radiate from the positive pole to a short distance ; but a proportion of 2000 mercury to 1 lead extinguished every trace of motion.

36. *Tin* acts also in the same way, and with nearly the same energy, as far as I could judge by the eye. It is certainly much inferior to zinc.

37. *Iron* communicates the property in question, though present in such minute quantity as not to be detected by prussiate of potash. On the other hand,\* *Copper* does not communicate it, though its proportion be increased to such a degree as to give a blue solution in nitric acid, and even to render the mercury quite sluggish.\*

38. Of the other metals I have tried, *Antimony* is the only one which appears to exert a perceptible action, and this is so slight (never amounting to more than a mere start, or slight convulsion of the surface at the first impression) that I am inclined to attribute it to impurities in the antimony used, especially as this metal stands very low in the scale of electro-

\* The amalgam of iron obtained in one experiment was a white friable solid of a lustre between silver and iron : the mercury being driven off by heat, the iron took fire, and glowed like a live coal till reduced to the state of black oxide, soluble in muriatic acid, having all its characters.

positive energy. Bismuth, silver, and gold, though present in considerable quantities in the mercury, impart to it no power of rotation whatever.

39. This property then of the metals, bears an evident relation to their electro-positive energies. It even affords something like a numerical estimate of them; rude indeed, and liable to a thousand objections, but still not without its value in our present state of complete ignorance on that most interesting of all chemical problems. If it be true, that the whole of chemistry depends on electrical attractions and repulsions, every thing which offers a prospect, however remote, of one day arriving at an exact knowledge of the intensities of these forces, must be regarded as of consequence. It may be objected, that it is only the excess of the electro-positive energy of the alloying metal over that of the mercury, or the alloy over the liquid, that we measure in these experiments, by the quantity of it required to impart a certain appreciable momentum. Yet it is something to have rendered it probable, that this excess in the cases of sodium, zinc, and lead, are in proportions not *very* remote from 1,600,000; 700,000; and 1000; or 1600, 700, and 1. The effect being purely mechanical, even the intensity of the motive forces exerted on a molecule of one of these metals could be determined, did we know the law of its action—but at least, in our ignorance of this, we are sure that it must be incomparably superior to gravity. A mass of mercury an inch in diameter alloyed with  $\frac{1}{100,000}$  its weight of zinc, revolved with a motion so rapid as to complete the transfer of particles floating in the liquid in less than a second across its surface. Now, even if we were to take the supposition of a uniform acceleration of the

motion of a molecule from one end to the other of this transfer, the intensity of gravity being taken at unity, that of the force accelerating each particle of the alloy would amount to

$$\frac{1 \text{ inch}}{16 \text{ feet} \times (1'')^2} = \frac{1}{12 \times 16} = 0.00521,$$

and each particle of zinc being loaded with 100,000 times its weight of inert matter, the intensity of the force, acting on its molecules, cannot possibly be so little as 521 times their gravity. But it is in all probability immensely greater. So far from being uniformly accelerated along their whole course, the molecules, if narrowly watched, will be evidently seen to move with less and less velocity as they recede from their point of radiation; and it is assuming little to suppose their velocity at a hundredth of an inch from this point double of their mean velocity with which they traverse the diameter. To produce this effect, the force must (if supposed to act uniformly through *this* small space) be increased 100 fold, or to an intensity upwards of 50,000 times that of gravity. Such considerations tend, if I mistake not, greatly to enlarge our views of nature, and to prepare us for the admission of the most extravagant *numerical* conclusions respecting bodies less within the reach of our senses. That such minute proportions of extraneous matter should be found capable of communicating sensible mechanical motions, and properties of a definite character, to the body they are mixed with, is perhaps the most extraordinary fact that has yet appeared in chemistry. When we see energies so intense exerted by the ordinary forms of matter, we may very reasonably ask, what evidence we have for the imponderability of any of those powerful agents to which so large a part of the activity of material bodies seems to be owing?

40. I was anxious to examine whether similar motions would be produced in other metals than mercury and its alloys, when in fusion. The foregoing experiments, indeed, leave little room to doubt their capability to do so; but the nature of the case throws great difficulties in the way of direct experiment. I have been successful hitherto only in the case of the fusible alloy of lead, tin, and bismuth, no mercury being present. This, with a little management, may be preserved tolerably clean of film and air bubbles, when kept in fusion under a boiling solution of sugar, acidulated with phosphoric acid, in which case the same circulation takes place as in the case of mercury, viz. from the negative to the positive pole. When solution of sugar alone however was used, the influence of the tin and lead became sensible, the predominant radiation being from the positive pole; a feeble counter-current being, however, observed from the negative.

41. The contact of the positive pole, in like manner, communicates peculiar properties to mercury, but less strongly marked, and which appear to depend, in part, on the film of oxide formed on its surface, and partly on an absorption of oxygen by the metal itself; a thing rendered not improbable by the analogy of silver and other metals, which when fused in contact with air, absorb oxygen without losing their metallic appearance. The facts I have observed are chiefly these:

42. Equal quantities of mercury were electrified for equal times in two separate capsules, under similar solutions of carbonate of soda, one in contact with the negative wire, and the other with the positive. On mixing them together, the mercury was acted on as if pure, and showed no signs of

containing sodium. Here, the mercury in contact with the positive pole had acquired a virtue capable of counteracting the effect of a considerable impregnation of sodium, which, had it not been counteracted, could not fail to be violent.

43. When mercury is kept in contact with the positive pole, the surface contracts a film of oxide of more or less considerable thickness. Now, break not only the contact, but the circuit. The mercury will be quite still ; but the moment it is touched with a clean metallic wire (not electrified), the oxide disappears rapidly at the point of contact, as if absorbed, and the remainder rushes in on all sides to supply its place, producing a system of current in the surface radiating towards the wire. It is not indifferent with what metal the contact is made ; potassium, sodium, barium, tin, and zinc, are those which produce the most violent action, the surface brightening instantly with a kind of flash like the *brandishing* of melted silver, tin being in this respect superior to zinc. The effect of iron is pretty considerable, that of copper less so, and of antimony and platina, none at all ; neither had phosphorus any effect.

44. The effect, therefore, depends on the oxidability and amalgamating property jointly ; and this points out the *modus operandi*. An amalgamation takes place at the point of contact, and this brings the oxidable metal into chemical contact with the oxide immediately around that point, which is instantly reduced. The motion of the surface is, however, doubtless an electric effect, for when mercury, *not* recently electrified is touched, under acids, &c. with metallic wires, the effects are not the same. The contact of copper, for instance, produces an immediate, and even strong radiating

current *from* the point of contact instead of *to* it, and this ceases the moment the contact becomes perfect by amalgamation, and cannot be renewed but by cutting off the amalgamated end, and making a fresh contact.

45. When mercury is electrified in contact with the positive pole under *certain* metallic solutions (nitrate of copper for instance), and the circuit broken, removing both wires, the current continues feebly for some time after the electric power is withdrawn, in the same direction (viz. from the point ( $z$ ) opposite to the negative pole. By degrees, it grows more forcible, and a film formed during the electrification is swept along to the point ( $c$ ) opposite the former position of the positive wire, where it accumulates, leaving at length, the portion of the surface at  $z$  quite bright. As soon as this happens, the currents increase considerably in strength, and radiate with great violence from the point  $z$ . This spontaneous action continues often for a long while. If the negative pole be made to act in succession, opposite to two points  $z$ ,  $z'$ , of the mercury, and be then quickly withdrawn and the circuit broken, both these points become centres, from which spontaneous currents radiate simultaneously in all directions. If the negative pole be made to act vertically over a large flat surface, when the circuit is broken, a violent spontaneous radiation emanates from the point immediately below the place where it was situated.

46. If the wires be only withdrawn so as to complete the circuit in the liquid, the film formed during the contact of the positive pole is swept to the point  $c$ , opposite that pole; and a violent current is established, radiating from  $z$  to  $c$ . If this be suffered to continue some time, and the circuit be then

broken, the motion continues as if the electricity still passed; but if the mercury be agitated, so as to break the crust collected at *c*, the regularity of the motion is disturbed: the surface of the mercury is thrown into a kind of fritillation, owing to an immense number of minute and very rapid vortices; and it is not till after some time that a regular and uniform direction of the currents is re-established.

47. These phenomena demonstrate the existence of a system of currents radiating *towards* every molecule of the crust on the surface. In consequence of this, so long as the latter is broken up into small portions and distributed over the whole surface, the currents are irregular and undecided; but as soon as these portions begin to be swept together and collected, they assume a uniform direction, *viz.* towards that part where, from contact of the vessel or other cause, they meet with no counter currents to oppose them. In what manner the crust acts is however still a little obscure: in all probability it forms a Voltaic combination with the mercury and the liquid.

48. In reasoning upon the facts detailed in this Paper, we have to consider, as probably materially influencing the results, first, the vast difference of conducting power between the metallic bodies set in motion, and the liquid under which they are immersed. This is not unlikely to enter as one of the essential conditions of the phænomenon, especially as it appears to result from all the experiments, that the peculiar action, whatever it be, by which the currents are produced, is exerted only at the common surface of the fluids. I have never been able to produce the least trace of such currents without the presence of a fluid metal. This leads us to conclude that a second essential condition is a perfect immiscibi-

lity of the conducting fluids, so as to render the transition from one to the other quite sudden. Besides these, a third essential condition is to be found in a certain chemical, or electrical relation between them. Under these conditions, it is by no means impossible, that the phænomena may admit of complete explanation from what we already know of the passage of electricity through conductors, and the high attractive and repulsive powers of the positive and negative electricities *inter se*. It is very possible, for instance, that a highly electro-positive body, as potassium, present in the mercury, may have its natural electric state exalted by its vicinity to the positive pole; and, being thus repelled, may take the only course the resistance of the metal on the one hand, and attraction of cohesion on the other, will permit; viz. along the surface, to recede from the positive pole. It *may* even act as a carrier of positive electricity, which *may* adhere to it too strongly to be transmitted through the mercury (which, though a good, is far from a perfect conductor;) and when arrived at the opposite side of the globule, may there, by the influence of the opposite pole, lose its exalted electrical state. This explanation tallies with that of other phænomena which have been attributed to a similar cause; I mean the tendencies observed in the vapours of electro-positive and electro-negative bodies to conductors electrified oppositely, which Mr. BRANDE has described in a Bakerian Lecture formerly read to this Society. Yet it must not be concealed that this explanation is beset with difficulties, and that the mode of action of the less-conducting medium in it is far from clear; it does not even appear why such a medium is at all necessary, unless we conceive it to retard, or otherwise modify the electric current, in its passage through

it, and dispose it thereby to ready combination with the metallic molecules.

49. Another course is doubtless open to us, which is to consider the action which takes place at the common surface of two unequally conducting media, as one, *sui generis*, and to depend on a new power of the electric current of a nature, bearing some analogy to the magnetic action, or possibly resulting from it; but this in the present state of our investigation would be too bold an hypothesis, especially as it is also a very vague one.

50. But whatever conclusions we may form, the phænomena are certainly interesting, and promise to afford abundant matter for future research. Meanwhile, it is not improbable that many phænomena of minute intestine motions usually attributed to capillary attraction, generation of heat, or other causes, may be referable to similar causes. One I cannot forbear to mention, from the striking *external* resemblance of the effect to some of those described in this Paper. I mean the motions described by M. AMICI in the sap of the chara, as originating in certain rows of globules disposed in the direction of the stream. The motion of the fluid in the vicinity of these globules has been attributed by M. AMICI himself to electricity developed in some unknown manner by them, and is so similar to what takes place when a stream of electricity is made to pass over a row of minute globules of mercury under a conducting medium, that one has difficulty not to presume an analogy in the causes.

J. F. W. HERSCHEL.

*Slough, January 6, 1824.*

## NOTE.

51. Since writing the above, Mr. FARADAY has been so good as to show me a Paper, published by M. SERRULAS, in the Journal de Physique for 1821 (vol. 93,) in which are related one or two of the appearances described in this Lecture, and other very curious ones referable to the same causes (though not apparently regarded by him as being so.) As the phænomena themselves are interesting, and the theory of them adopted by him is (as I shall easily show) insufficient, I shall be pardoned for extracting the whole passage from his Memoir ; regretting at the same time not having been able to find a former Paper on the subject, mentioned by him, in which his explanation is given at full length.

52. The phænomena in question relate to the singular gyro-tory motions assumed by alloys of potassium when floated in small fragments on mercury under water. After noticing those of the alloy of bismuth, which he describes as particularly forcible and lasting, he goes on to say,

53. " Ne seroit-il pas intéressant d'étudier l'action électrique qui se manifeste dans cette circonstance pendant l'oxidation du potassium." — " Elle me semble digne d'attention pour sa liaison avec la décomposition de l'eau dont elle depend uniquement.      \*      \*      \*      \*

54. " La pellicule légère qui se forme dans ce cas n'est que le bismuth divisé provenant de l'alliage retenant entre ses molécules des bulles d'hydrogène extrêmement fines. Cette pellicule, comme je l'ai dit, est attirée avec une grand promptitude par les substances métalliques mises en contact avec le

mercure sur lequel les fragmens d'alliage sont en mouvement.

55. " J'ai du considérer cette pellicule comme jouissant de l'électricité positive, attendu qu'elle se porte vivement vers l'extrémité negative d'une cuve en activité, et qu'elle est au contraire puissamment repoussée par le pole positif. Si les deux conducteurs touchent seulement l'eau du bain, l'attraction et la repulsion ont lieu dans le sens indiqué. L'effet est encore le même si l'un des fils touche le mercure, et l'autre l'eau. La pellicule se fixe au pole negatif d'où elle est chassée avec force par l'approche du pole opposé. Elle s'écarte, et l'hydrogène de l'eau décomposée se dégage sur ses bords qui dans ce cas font partie du conducteur et le terminent. Si les deux fils plongent dans le mercure il est bien entendu qu'il ne se manifeste plus rien.

56. " Quand, au lieu d'eau simple, le bain de mercure est couvert d'une dissolution peu chargée du chlorure de sodium, le tournoiement des fragmens est plus lent. L'hydrogène produit se trouve engagé et retenu presqu'entièrement par la pellicule du bismuth ; l'eau en devient nebuleuse. A l'instant où l'on a plongé dans le bain une tige métallique, on remarque autour de celle-ci un frémissement ; les mouvements cessent et sont arrêtés tant que la tige reste plongée ; elle fixe la pellicule dans toute l'étendue du bain ; les fragmens d'alliage y sont emprisonnés ; mais aussitôt que la tige est retirée, *l'effluve d'hydrogène écarte la pellicule, et les mouvements recommencent.*

57. " Un fil plongé sur un point quelconque d'un bain ou tournoie l'alliage, même dans un endroit éloigné de ce tournoiement, la partie plongée de ce fil se couvre en peu de

temps d'une multitude des bulles d'hydrogène. Ne pourroit-on pas encore d'après cette observation, *qui prouve que toute la surface du bain est parcourue d'hydrogène*, ne pourroit-on pas trouver dans l'émission rapide et abondante de ce gas la cause de l'électricité, quand on considère que l'air atmosphérique dirigé avec une soufflet sur un carreau de verre donne a ce carreau l'électricité vitrée; ou bien cette effluve d'hydrogène qui pousse vivement sur le mercure les molecules de bismuth non amalgamé, qui les réunit sous forme de pellicule, produit entre les deux métaux un frottement qui développe cette électricité."

58. From these passages it seems natural to collect, that M. SERRULAS conceives, 1st, the production, motion, &c. of the pellicle on the surface to originate in the actual mechanical impulse of streams of hydrogenous matter (*effluve d'hydrogène*), radiated in all directions from the potassium in the moment of its oxidation. That, 2ndly, this bodily radiation of hydrogen is propagated along the surface to any distance. That, 3rdly, the hydrogen disengaged in bubbles from a metallic wire plunged into the mercury is this actual radiant hydrogen, conveyed and collected on its surface from all parts of the mercury. That, 4thly, the friction of the hydrogen so radiated produces the electricity, and not the electricity the hydrogen. And, lastly, that the gyration of the fragments themselves is a consequence of the re-action of the hydrogen they dart out during their oxidation by the water.

59. All these phænomena, however, are much better accounted for on the principles of this Lecture, from a knowledge of the properties conferred on mercury by alloying it with potassium; but, first, it is necessary to premise, that the mere

contact of a metal capable of amalgamating, even for an instant, communicates its peculiar properties, almost in the moment of contact, to the whole mass. The experiments in Art. 33, abundantly prove this ; and it may be readily shown also by the following. Let a quantity of mercury be placed in a vessel of muriatic acid ; no action takes place ; but if touched with a zinc wire it presently becomes covered with bubbles, copiously disengaged from every part of the surface.

60. In the circumstances of M. SERRULAS's experiments, it is therefore obvious that his mercury must have been always sensibly impregnated with potassium and the supernatant liquid, a solution of potash ; and that it was so, is proved by the effects of the electric current, which agree precisely with those I have stated, as being always produced in such circumstances (Articles 18, 28;) but the cause assigned to these effects by Mr. S. viz. the electro-positive energy of *the pellicle*, is proved not to be the real one by the simple fact, that the violence of the motion is always proportional to the cleanliness of the surface, and is greatest when there is no pellicle at all ; besides which, the pellicle *here* consisted of metallic bismuth, a substance incapable of producing any such effect as shown in Art. 38.

61. The gyration of the fragments is produced as follows : a strong Voltaic excitement takes place at the point of contact of two metals so different as mercury and potassium. The mercury becomes strongly positive, and the floating fragments negative. The circuit is completed by the alkaline liquid ; and the mercury, being alloyed with a portion of potassium, and being itself the positive pole of the combination, we have here the case of Art. 21 ; and the result, as stated

by M. SERRULAS, is precisely as in that experiment, the currents radiating from the point of immersion. These once produced, drive before them the fragment in which they originate, in the direction in which it exposes the greatest surface to their action.

62. The attraction of the pellicle to a metallic rod plunged into the mercury, is also a direct consequence of the alloy of potassium present in the mercury, as is also the disengagement of gas from the wire. It is, in fact, precisely the experiment described in Art. 25, and has nothing whatever to do either with the floating fragments, or with any hydrogen they may be discharging at the time, farther than that their contact serves to furnish potassium to the mercury.

63. It is needless, therefore, to push this examination farther, as all the phænomena observed by Mr. S. are only particular cases of those I have described. With regard to the radiant hydrogen producing currents by its impulse, I would ask how it happens that currents are produced (when the positive pole is placed in contact), while a thick and tough coat of oxide covers the whole surface; and, one would think, must effectually defend it from the action of the hydrogen. Yet we have seen, in Art. 18, that the currents continue their course under this crust; and it will hardly be contended, that the hydrogen finds a passage between the oxide and the metal.

J F. W. H.

*London, Jan. 13, 1824.*